Harvard-Smithsonian Center for Astrophysics

Precision Astronomy Group

MEMORANDUM

To: K.J. Johnston
From: R.D. Reasenberg
Subject: Draft report of the committee on Solar Radiation Pressure
Date: 20 April, 1999

I. Membership.

Michael Mook <mmook@space.nrl.navy.mil>
Marc Murison <murison@aa.usno.navy.mil>
Bob Reasenberg <reasenberg@cfa.harvard.edu>, Chair

II. Background and Overview.

In 1996 (and perhaps earlier), it was hypothesized by several members of the Project Team that smooth rotation of the spacecraft (cf. frequent use of attitude control jets) would result in an improved information return from the mission. In November of ‘96, I realized that the solar radiation pressure on the FAME spacecraft could be used to provide much smoother rotation than the gas jets that precessed Hipparcos. Solar torque is also likely smoother than the ion engines that have been discussed for precessing GAIA (Gilmore, SPIE Conf. 3350, Kona, 3/98). TM97-03 analyzes the use of solar torque (with results confirmed by Marc Murison using different geometry and computer algebra, which allowed him to do the final integral analytically instead of numerically as in TM97-03), and shows that for a reasonable size shield, (1) the torque is of about the correct order, but larger than needed for a slowly spinning (2 hour period) spacecraft, and (2) the torque can be changed over a large range by adjusting the "sweep back" angle, β, of the shield.

The hypothesized importance of the smooth rotation of the instrument has been confirmed by Chandler and Reasenberg in a series of mission covariance studies. These are described in three SAO TMs and in a draft paper that has been circulated to the Project Team by Ken Seidelmann. There are now plans to redo the studies to add refinements and make the cases both more systematic and more applicable. In the mean time, a mildly revised version is (or will soon be) available on the FAME web site as TM99-04.

Following the publication of TM97-03, there remained three principal problems: (1) For the slow nominal spin rate of the time, it needed to be shown that β could be set accurately enough. (2) The motion under constant solar torque needed to be described in more detail. (3) The stochastic component of the torque needed to be investigated, including both fluctuations in the solar flux and the solar wind contribution (which is essentially all stochastic). The present state of the solution to these problems is addressed below, followed by a discussion of aspects of the use of solar radiation pressure to precess FAME.

III. Setting of β.

If we assume that the precession is to be 0.5 deg per spacecraft rotation (which has long been the nominal, but has not been shown to be optimal), then the required torque is proportional to the square of the spin rate. Changing the spin period from about 140 minutes to 20 minutes removed the need for precise setting of β. Increasing the spin period to 40 minutes has made the problem a little more difficult. Michael Mook has suggested that the large panels of the solar shield be fixed and the torque adjustment be made with small tiltable sections at the ends of the panels. This seems to solve the problem, particularly since the precession rate is not critical. All that is required is that it not change much (or often) without our having independent knowledge of the change.

IV. Equations of motion.

TM99-03 provides a derivation of the equations of rotational motion of the spacecraft in the case of a moving Earth, but neglecting the Earth's orbital eccentricity (which is not likely relevant for short batches -- say half a day). It also provides a low-order analytic solution of the equations of motion. Finally, TM99-03 provides a numerical confirmation and extension to a solution of higher order in small quantities. In the TM, it is shown that there is a small, predictable deviation from the uniform motion of the spin vector around the Sun direction. This has no adverse effect on the FAME mission (but must be accurately represented in the data analysis).

V. Stochastic pressure.

Marc Murison has obtained 350 days of data from the VIRGO mission. These data represent the total solar irradiance at one minute intervals. He has developed a numerical integration code for the full set of six equations of rotational motion of the instrument and has used the VIRGO data to provide the driving torque. His results are expected soon.

Marc has pointed out that the solar wind is stopped at the bow shock, and normally would not get to the FAME spacecraft. However, it will still be necessary to investigate the small portion of the wind that does get through to determine the impact, if any, on the rotation of the spacecraft.

VI. Discussion.

The viability of the use of solar radiation torque now pivots on the results of the study of the stochastic pressures. We continue to believe that the stochastic torque will not have a first-order effect on the scan-direction observable, although it will have a first-order effect on the cross-scan observable. However, even a second-order effect could be important since the single-measurement precision is smaller than 1 mas.

It now seems likely that, for the reduction of the FAME data, we will need to numerically integrate the (six) equations of motion for the rotation of the spacecraft. Further, internal damping may be needed on the spacecraft to counter the effects of stochastic torque, which will excite Eulerian nutation. If the stochastic torque is large at high frequency (i.e., several times the rotation frequency), it may be necessary to use a large number of parameters per rotation to adequately represent its effect on the spacecraft rotation. In this case, the parameter estimation may be burdensome in the sense that the inclusion of the required new parameters, along with those already part of the model, increases significantly the statistical uncertainty in the *a posteriori* knowledge of the spacecraft rotation. In this situation, consideration should be given to the use of a solar irradiance detector mounted on the front of the spacecraft. Such a detector might consist of a large-pixel CCD illuminated through a pin hole. A better design might be four pin holes, each with a different colored filter.